HAMPTON UNIVERSITY

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SUMMARY OF RESEARCH

# MIXING, NOISE AND THRUST BENEFITS USING CORRUGATED DESIGNS

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# MIXING, NOISE AND THRUST BENEFITS USING CORRUGATED DESIGNS

## I. SUMMARY OF RESEARCH

Originally, the NASA grant, NAG-1-1936, was a 2-year FY 1997 Partnership Award that was extended for 1 year. This grant was the primary initial funding for the Fluid Mechanics and Acoustics Laboratory at Hampton University (HU/FM&AL) which was employed in fulfillment of research supported by another NASA grant, NAG-1-1835, FAR Award, 1996-99. The HU/FM&AL, established at Hampton University in June of 1996, is currently working under two further NASA grants. In addition, the FM&AL jointly conducted research with the Central AeroHydrodynamics Institute (TsAGI, Moscow) in Russia under a 2.5 year Civilian Research and Development Foundation (CRDF) grant #RE2-136, 1996-99. The reported grant was the foundation of the HU/FM&AL in its initiation and growth, and the next two NASA grants for the HU/FM&AL, NAG-3-2249, FAR Award, 1999-01, and NAG-3-2422, FAR Award, 2000-02, are a continuation and development of the research projects under the reported grant. These projects are directed toward the analysis of several concepts for nozzle and inlet performance improvement and noise reduction from jet exhausts. Currently, as a primary research partner, the HU/FM&AL is also conducting a new project for joint research between the GRC and Institute of Mechanics at the Moscow State University in Russia under a 1 year CRDF grant # RE1-2068. The FM&AL also initiates new joint research between the HU/FM&AL, the Hyper-X Program Team at the LaRC, and the Central Institute of Aviation Motors (CIAM), Moscow, Russia in the field of optimization of fuel injection and mixing in air-breathing propulsion systems. The main results of theoretical, numerical simulation and experimental tests obtained in the previous research are in the papers [1-5] and patents [6,7].

The goals of the HU/FM&AL programs are twofold: **1)** to improve the working efficiency of the HU/FM&AL team in generating new innovative ideas and in conducting research in the field of fluid dynamics and acoustics, basically for improvement of supersonic and subsonic aircraft engines, and **2)** to attract promising minority students to this research and training and, in cooperation with other HU departments, to teach them basic knowledge in Aerodynamics, Gas Dynamics, and Theoretical and Experimental Methods in Aeroacoustics and Computational Fluid Dynamics (CFD). The research at the HU/FM&AL supports reduction schemes associated with the emission of engine pollutants for commercial aircraft and concepts for reduction of observables for military aircraft. These research endeavors relate to the goals of the NASA Strategic Enterprise in Aeronautics concerning the development of environmentally acceptable aircraft. It is in this precise area, where the US aircraft industry, academia, and Government are in great need of trained professionals and which is a high priority goal of the Minority University Research and Education (MUREP) Program, that the HU/FM&AL can make its most important contribution.

This project already benefits NASA and HU because:

First, the innovation, testing, and further development of new techniques for advanced propulsion systems are necessary for the successful attainment of NASA goals. Particularly, the NASA Long Term Goals in Aeronautics and Space Transportation Technology (ASTT) including Global

Civil Aviation, Revolutionary Technology Leaps, Access to Space, R&D Services, and the economic competitiveness of the US Aircraft Industry in the 21st century.

Secondly, the joint theoretical and experimental research and training by the GRC-HU Teams aids: using advanced methods and experience in Aerospace Engineering for domestic industries and training of HU students for interesting innovative work in the numerical simulation field as well as engineering and experimental research. HU students use and modify existing numerical codes of the NASA Langley Research Center (LaRC) for the solution of actual applied aerodynamics problems.

The main achievements for the reporting period in the development of concepts for noise reduction and improvement in efficiency for jet exhaust nozzles for aircraft engines are as follows:

**1) Publications:** A paper has been published in the AIAA Journal, 1997, [1] and a paper has been published in the Proceedings of the 136th Meeting of the Acoustical Society of America, 1998, [2]. In addition, the AIAA Papers #98-2260 [3], #98-2261, [4], and #99-1924 [5] have been presented at the 4$^{th}$ and 5th AIAA/CEAS Aeroacoustics Conferences respectively.

**2) Patents and Inventions:** Two patents were granted on July 20, 1999 [6], and July 4, 2000 [7], and three patent applications [8-10] have been accepted and awarded by NASA Certificates of Recognition.

**3) Reports/presentations without publication:** Twenty-two reports have been presented at NASA LaRC, GRC and Hampton University. These include 12 reports at the Workshop/Seminar: "NASA Langley Research Center- Hampton University Partnership in Fluid Mechanics and Acoustics" on May 15-16, 1997, at Hampton University. This workshop attracted participation of HU students, leading scientists and professors from NASA LaRC, Hampton University and TsAGI. Those present included Drs. Dennis M. Bushnell, John M. Seiner, Jay C. Hardin, Kenneth S. Brentner, and Douglas M. Nark from NASA LaRC. Also Professors Vladimir M. Kouznetsov, Boris M. Efimtsov, Victor F. Kopiev, and Aron S. Ginevsky of TsAGI and Mikhail Gilinsky, Abolghassem Miamee, Alkesh Punjabi, and Frank P. Kozusko from HU. Five reports were presented at Acoustics Seminars in the TsAGI, Moscow, on November 17-22, 1997, during a visit of the US Team members to Russia (Drs. M. Gilinsky and J.M. Seiner).

**4) Proposals and Grants:** Since 1997, 5 proposals have been submitted by the HU/FM&AL members to NASA programs, 5 for the CRDF, one for the AFOSR, and one for the NSF. Two NASA Faculty Awards were granted on January 1999 (NAG-3-2249) and on April 2000 (NAG-3-2422). A CRDF Award #RE2-136 (1996-99) and a Young Investigator Program Award for a 3 month visit of the Russian scientist, Dr. Sergey A. Chernyshov, to the HU/FM&AL (03/99-05/99) have been granted. The new CRDF 1-year grant #RE1-2068 for joint research between NASA GRC-Hampton University-Institute of Mechanics at the Moscow State University (Russia) was awarded in July 2000.

**5) Interaction with other institutions:** At the present time, the HU/FM&AL interacts with several US and foreign institutions, and conducts joint research projects or exchanges by

consultations. The main institutions and appropriate scientists are: from **NASA Langley Research Center**, (Drs: Dennis M. Bushnell, Joe W. Posey, Lucio Maestrello, Douglas M. Nark, Christopher L. Rumsey, Charles R. McClinton, David E. Reubush, Robert Grandle, et al).; from **NASA Glenn Research Center**, (Drs: Isaiah M. Blankson, Robert C. Hendricks, Grigory Adamovsky, Mary Jo Long-Davis et al.); from **Mississippi State University,** (Drs: John M. Seiner, Michael K. Ponton, Larry S. Ukeiley et al).; from **North Carolina A&T State University,** (NASA Center for Aerospace Research, Dr. Frederick Ferguson et al.), from **Toronto State University, Canada,** (Aerospace Center, Dr. Alexander L. Gonor et al.); in Russia: from **Moscow State University** (Academicians: Gorimir G. Chernyi, Vladimir A. Levin, Alexander I. Zubkov, Samvel S. Grigoryan, Drs: Alexander I. Shvets, Valery G. Gromov, Vladimir I. Sakharov, et al.), from the **Central AeroHydrodynamics Institute**, TsAGI, Moscow, (Drs: Vladimir M. Kouznetsov, Victor F. Kopiev, Sergey A. Chernyshov, Boris M. Efimtsov, et al.); from the **Central Institute of Aviation Motors**, CIAM, (Drs: Alexander N. Krayko, Viacheslav A. Vinogradov, Valeri I. Kopchenov et al) .

**6) Laboratory improvement:**

**a)** At the present time, the basic foundation for the HU/FM&AL at Hampton University, i.e. good facilities for theoretical and experimental research, exists. The HU/FM&AL headquarters is located in room #503 in the Olin Bldg. Four computers with necessary supporting equipment are installed in the office: three SGI Indigo-2 connected with a Laser printer, ADP QMS Inc., and a Dell Computer connected with a Canon C5500 Fax/Printer/Scanner/Copier. All computers have access to the HU network and to the NASA GRC and LaRC networks through Internet. A Tektronix Phaser 850 color printer is connected with all computers through Internet as well. Modern software such as F90 compilers and TECPLOT-8 of the AMTEC Inc. is provided for all SGI computers for visualization and representation of numerical results. The HU/FM&AL computer lab intends to extend its capacities by purchasing several additional software packages and supplies using current grant and some additional HU funds.

**b)** The Hampton University Low Speed Wind Tunnel (HU/LSWT) is installed in the Experimental Hall, (room #124) in the Olin Bldg. NASA LaRC loaned this tunnel to the HU/FM&AL. The tunnel is a small-scale working model of the large scale LSWT at NASA LaRC. Basically, the NASA/LSWT is for experimental aerodynamic problem investigations. However, the HU/LSWT will be employed for aeroacoustic testing as well. Thus, the original HU/LSWT construction was changed in accordance with the size of the Experimental Hall and with the purpose of noise reduction from the fan motor and for reduction of the vibration influence of this motor on the main portion of the wind tunnel with the test section.

**7) Theory and Numerical Simulations:** Analytical theory, numerical simulations, comparison of theoretical with experimental results, and modification of theoretical approaches, models, grids etc. have been conducted for several complicated 2D and 3D nozzle and inlet designs. This research has utilized NASA codes based on full Euler and Navier-Stokes solvers: CFL3D, CRAFT, GODUNOV, HU/FM&AL and others.

**8) Experimental Tests:** Experimental acoustic tests have been conducted for different Bluebell nozzle designs and nozzles having Screwdriver or Axisymmetric Plug and Permeable Shells in

the small and large anechoic facilities at the NASA LaRC and TsAGI, Moscow. A small-scale model of the NASA Low Speed Wind Tunnel (LSWT) has been installed in the Experimental Hall of the HU FM&AL (June 1999). The necessary equipment for experimental tests was provided and the first laboratory tests and calibrations were conducted. Several Möbius shaped screws for the mid class of the kitchen mixers have fabricated and tested with different volumes of the vessels and particles.

**9) Teaching and Training:** Four lecture courses were conducted for graduate students of Mathematics and Computer Science Departments in the field of Fluid Mechanics and Acoustics, and eight supported courses were conducted for undergraduate students of the Engineering and Technology School in the field of multi-phase flows. Three students were involved in the experimental work for wind tunnel installation and test preparation and three students were involved in numerical simulations of the problems and grid generation for these problems.

**10) Students Research Activity:** Four Hampton University graduate and five undergraduate students were involved in fulfillment of this project: a) Graduates- Tejan Tingling, Kaushal Patel, Lotlamorang Gilbert Mosiane, and Moniruzzaman Khan; b) Undergraduates- Kristy Brewington, Christopher Payne, Brian Lee, Christopher Nettle, and Calvin Coston.

**11) Financial Distribution:** The total amount of the Partnership Award, $360K, was spent uniformly during the 3 years. Approximately 50% (178K) provided salaries for the main researchers involved in this project: (Drs: M. Gilinsky, D.M. Nark, F.P. Kozusko, and J.C. Hardin). Approximately 7% (27K) was spent for student wages and aids, ~4% (13K) went for payroll/benefits, ~7% (26K) went for supplies, equipment and travel, and approximately 32% (116K) were indirect costs.

## II. ENCLOSURES

Because this grant supported the NASA FAR Award, NAG-1-1835, the main research results and approaches are the same for both projects. Thus, some details of research results will be omitted which were presented in appendix A of the final report [11] for the FAR Award. Copies of the papers published and of the two patents awarded during the reporting period are contained in Appendix A.

## III. CONCLUSION

The current research is focused on the development of the Bluebell nozzle and Möbius strip concepts through numerical and experimental simulations. The Bluebell nozzle concept, for which a patent application has been filed through NASA, can be utilized as a noise reduction concept for the separated flow co-annular nozzle in the NASA AST program. In this research, students were involved in tests at the NASA and HU experimental and numerical simulation tests. Boeing, GE Aircraft Engines and Pratt & Whitney Aircraft and other aviation companies have expressed interest in the development of this concept for subsonic commercial engine technology. Of course, this depends upon a successful outcome of testing and analysis. The application of the research to the future supersonic US aircraft engine design is also very promising on the basis of the preliminary positive results of the experimental and numerical simulations. The primary goals

formulated in the proposal for the NASA Partnership Awards Program in 1997 were achieved during the reported period of performance. In particular, in this period, the Fluid Mechanics and Acoustic Laboratory at Hampton University was developed and became an effective subdivision of the School of Engineering and Technology conducting very important research into applied problems in Aerospace Engineering and Aeronautics for Rocket, Aviation and domestic industries. At the present time, the HU/FM&AL is involved in joint research with two NASA agencies (GRC and LaRC) and three Russian institutions. These Russian institutions, Institute of Mechanics of Moscow State University (IM/MSU), Central Institute of Aviation Motors (CIAM), and Moscow Institute of Physics and Technology (MIPT), are highly experienced in the field. At present, the Laboratory can undertake research into complicated problems in Aviation and Aerospace Engineering using theoretical, numerical simulation and experimental approaches.

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